Production process of a flat suspended micro-structure using a sacrificial layer of polymer material and component obtained thereby

Background of the invention

The invention relates to a production process of an integrated micro-system type component, comprising a flat suspended micro-structure, using a sacrificial layer of polymer material deposited on a substrate and having side walls confining the flat suspended structure, process successively comprising a planarization step, a deposition step of a formation layer of the suspended structure, an etching step of at least one opening of the formation layer up to the level of the front face of the sacrificial layer and a dry etching step of the sacrificial layer.

State of the art

Many integrated micro electro-mechanical systems (MEMS) comprise flat suspended micro-structures. This is for example the case of suspended volume actuators, sensors, switches, variable capacitors, inductors or acoustic wave resonators. In micro-technology or microelectronics, suspended micro-structures are achieved by the use of a sacrificial layer. The conventional steps for obtaining a suspended micro-structure are represented, in simplified form, in figures 1 to 5. In a first step represented in figure 1, a layer 2a is deposited on a substrate 1. The layer 2a is typically made of polymer material, silicon oxide or tungsten. The second step, represented in figure 2, consists in lithographing and etching the layer 2a so as to form a sacrificial layer 2

covering a part of the substrate 1 whereon the suspended structure has to be formed. Then, in a third step represented in figure 3, a formation layer 3 of the suspended structure is deposited on the substrate 1 and on the sacrificial layer 2. The formation layer 3 can be conducting or dielectric or formed by a stack of several different layers. The fourth step, represented in figure 4, consists in lithographing and etching the formation layer 3 up to the level of the front face of the sacrificial layer, so as to confine the suspended structure 5 by openings 4 in the formation layer 3. In a fifth step, represented in figure 5, the sacrificial layer is removed by dry etching or wet etching so as to form a free space between the substrate and the suspended structure 5, thus releasing the suspended structure.

The material forming the sacrificial layer is chosen so that etching thereof is selective with respect to the material for achieving the micro-structure. For example the sacrificial layer can be made of silicon oxide ($Si0_2$) and the suspended structure can be made of polysilicon. A second combination comprises a sacrificial layer made of polymer material and a suspended structure made of $Si0_2$. A third possibility consists in using a sacrificial layer of polymer material and a suspended structure made of metal. The use of a sacrificial layer that is removed by wet etching, for example $Si0_2$ in a hydrofluoric acid (HF) based bath, gives rise to sticking problems of the structures in the removal step. This problem is generally associated with capillarity effects and surface forces. Consequently, a sacrificial layer of polymer material that is easily removed by plasma etching, for example of the oxygen plasma type, is increasingly used. As this etching is performed dry, sticking problems are eliminated.

The geometric shape and cross-sectional profile of the suspended structure has great consequences on buckling or displacement of the suspended

structure according to an external excitation (electric, thermal, acceleration, pressure, etc...).

The profile of the suspended structure 5, in a plane perpendicular to figure 5, is perfectly defined in the lithography step. Its profile in the plane of figure 5 on the other hand depends on the bottom layers, and in particular on the sacrificial layer on which the suspended structure is built. In the case of use of a sacrificial layer of polymer material, the profile is very often greatly accentuated by the creep of the material when annealing is performed. However the exact profile of the suspended structure has repercussions on checking of the system. Ondulations of the micro-structure, caused by the shape of the sacrificial layer, in fact make the stiffness of the final device and its deformation according to the excitation conditions difficult to know. The space comprised between the suspended structure and the substrate is also influenced by the outline. Moreover, the embedding of the micro-structure depends on the tilt of the suspended structure, which also depends on the profile. Not knowing the exact profile leads to a large discrepancy between simulations and experimental measurements of the device and to risks of stress concentrations at the embeddings and on the mobile structure. Especially, this makes the devices extremely sensitive to process variations.

In order to be able to check the profile of the final suspended structure better, it is recommendable to include a sacrificial layer planarization step. However, polymers are materials which are very difficult to planarize. Chemical mechanical polishing (CMP) tests show very mediocre results, for example tear-off of the resin when polishing, irregularity of planarization or incrustation of colloidal silica (contained in the CMP planarization product) in the polymer, then occurring when the sacrificial layer is removed.

Other dry planarization tests (planarization on abrasive film) also gave mediocre results. A good rectification of the polymer was obtained, but at the price of a very large number of scratches on the plane of the chip and tear-offs on the polymer pads, as well as incrustation of the abrasive material in the polymer.

US Patents 6,361,402 and 6,150,274 propose polymer planarization processes. However, these processes do not provide a simple solution. Moreover, these processes are not suitable for all types of polymer (photosensitive resin, polyimide, etc...) and for all the annealing conditions of these polymers. Indeed, in certain cases, the polymer may have to be annealed at a higher temperature than its temperature of use, for example by annealing at 300°C of a photosensitive resin the temperature of use whereof is conventionally less than 200°C, to enable a plasma enhanced chemical vapor deposition (PECVD) process to be used at 300°C on the polymer. These thermal treatments may lead to the polymer being denatured and make it almost impossible to planarize. In a general manner, and in particular when they are annealed at high temperature, polymers are very sensitive to tearing and tend to trap the abrasive compounds contained in the planarization products which are deposited under the mobile structure when the removal step is performed.

Object of the invention

The object of the invention is to remedy these shortcomings and, more particularly, to provide flat suspended structures using a planarized polymer sacrificial layer.

According to the invention, this object is achieved by the fact that the process comprises, between deposition of the sacrificial layer and the planarization step, a deposition step, on at least a part of the substrate and of the front face of the sacrificial layer, of an embedding layer presenting a larger thickness than the thickness of the sacrificial layer, so that, after the planarization step, the front faces of the sacrificial layer and of the embedding layer form a common flat surface, the formation layer of the suspended structure being deposited on the front face of the common flat surface.

According to a preferred embodiment, the planarization step successively comprises a chemical mechanical polishing sub-step of the embedding layer and an etching sub-step of the embedding layer so that the front faces of the sacrificial layer and of the embedding layer form a common flat surface.

According to a development of the invention, the side walls of the sacrificial layer are confined by etching by means of a mask formed on the front face of a layer made from polymer material by deposition, lithography and etching of a temporary layer, deposition of the embedding layer being performed on the assembly formed by the sacrificial layer and the mask, the mask being eliminated in the course of the planarization step.

According to another development of the invention, the component comprising salient elements on the substrate, the process successively comprises, before deposition of the sacrificial layer, deposition on at least one zone of the substrate designed to be covered by the sacrificial layer and comprising salient elements, of a base layer presenting a larger thickness than the thickness of the salient elements, and an additional planarization step, by chemical mechanical polishing, of the base layer, so that the front faces of the base layer and of the salient elements form a common flat surface.

According to a component achieved by a process according to the invention, the two faces of the formation layer of the suspended structure are totally flat.

Brief description of the drawings

Other advantages and features will become more clearly apparent from the following description of particular embodiments of the invention given as non-restrictive examples only and represented in the accompanying drawings, in which:

Figures 1 to 5 represent a process, according to the prior art, for achieving a component comprising a suspended structure.

Figures 6 to 11 represent different steps of a particular embodiment of a process according to the invention.

Figures 12 to 14 represent steps of another particular embodiment of a process according to the invention.

Figures 15 to 19 represent steps of a third particular embodiment of a process according to the invention.

Figures 20 to 23 represent steps of a fourth particular embodiment of a process according to the invention.

Description of particular embodiments

Figure 6 represents a sacrificial layer 2 arranged on a substrate 1. The side walls 10 of the sacrificial layer 2 have been confined by lithography and etching, as in figure 2. The flat suspended structure designed to be formed on

the sacrificial layer 2 is confined by the side walls 10 of the sacrificial layer 2. Figure 7 represents a deposition step, on at least a part of the substrate and of the front face of the sacrificial layer 2, of an embedding layer 6 presenting a larger thickness than the thickness of the sacrificial layer. Typically the thickness of the embedding layer 6 is 1.7 times greater than the thickness of the sacrificial layer 2. The embedding layer 6 must be arranged in such a way as to envelop the sacrificial layer 2 and to prevent lateral displacement of the sacrificial layer 2. The embedding layer 6 can cover and surround the sacrificial layer 2 totally. It can also only cover a limited strip of the sacrificial layer 2 and extend, at the ends of this strip, onto the adjacent zones of the substrate 1, on each side of the sacrificial layer 2. The material of the embedding layer 6 must be a material enabling a planarization process to be used, in particular of the CMP type, for example SiO_2, silicon nitride or aluminium. As represented in figure 8, a planarization step of the whole of the embedding layer 6 and of the sacrificial layer 2 is performed so that the front faces of the sacrificial layer 2 and of the embedding layer 6 form a common flat surface. The planarization step must be stopped as soon as the front face of the sacrificial layer 2 is completely uncovered. In this way, the fluctuations of thickness of the sacrificial layer 2 are evened out and the sacrificial layer 2 and the embedding layer 6 form a common flat surface. Continuing the planarization step beyond this limit increases the risk of damaging the quality of the surface of the sacrificial layer 2 and of degrading the flatness.

Figure 9 represents a deposition step of a flat formation layer 3 for formation of the suspended structure on the front face of the common flat surface of the sacrificial layer 2 and the embedding layer 6. Unlike the prior art (figure 3), deposition of the formation layer 3 is performed on a single plane. A fourth step, represented in figure 10, consists in etching at least one opening 4 in the formation layer 3 up to the level of the front face of the sacrificial layer 2.

Then, in a fifth step represented in figure 11, dry etching of the sacrificial layer 2 is performed. The flat formation layer 3 then forms the flat suspended structure 5.

A component achieved by the process according to the invention comprises a formation layer 3 of the suspended structure 5 presenting two flat faces, the front face and the back face arranged on the embedding layer 6.

The planarization step can comprise chemical mechanical polishing (CMP) and, in particular, consists only in chemical mechanical polishing. A process of the CMP type consists, in known manner, in holding the object to be planarized against a wetted rotary polishing plate in a polishing bath containing abrasives and an acid or alkaline solution. The abrasives are typically aluminium- or silicon-base particles. The layer to be planarized is thus chemically modified by the liquid and then removed by the particles of the abrasive. Applying a CMP type process directly on the sacrificial layer 2 is liable to damage the sacrificial layer 2, even in the presence of an embedding layer 6, in particular by incrustation of residues of the abrasive.

In another particular embodiment of the process of the invention, represented in figures 12 to 14, contact of the sacrificial layer with the polishing bath is avoided. The initially deposited embedding layer 6 in fact presents a thickness about 1.7 times greater than the thickness of the sacrificial layer 2 (figure 12), and the planarization step comprises a chemical mechanical polishing sub-step enabling a flat surface of the embedding layer 6 (figure 13) to be obtained, and an etching sub-step of the embedding layer 6 uncovering the sacrificial layer 2 so that the front faces of the sacrificial layer 2 and of the embedding layer 6 form a common flat surface (figure 14).

In another particular embodiment of a process according to the invention, represented in figures 15 to 19, initial etching of the sacrificial layer 2 is performed by means of a mask 7 previously formed on the front face of the sacrificial layer 2 by deposition, lithography and etching of a temporary layer (figure 15). The temporary layer can be made of dielectric or metal material (for example chromium, aluminium, etc...). The typical thickness of the temporary layer is comprised between 10 and 50 nanometers. As represented in figure 16, the mask 7 enables the side walls 10 of the sacrificial layer 2 to be confined. Deposition of the embedding layer 6 is then performed on the assembly formed by the sacrificial layer 2 and the mask 7 (figure 17). The complete planarization step is then performed in two sub-steps. A first planarization sub-step can be performed by a CMP type process, without any risk of damaging the sacrificial layer 2, because the sacrificial layer 2 is protected by the mask 7 (figure 18). A second planarization sub-step consists in eliminating the mask 7, preferably by dry or wet etching, as represented in figure 19. The fabrication process of the suspended structure can then be continued by the steps represented in figures 9 to 11, described above.

If the component comprises salient elements 8 on the substrate 1, as represented in figure 20, the process for producing the suspended structure can comprise additional steps before deposition of the sacrificial layer 2. In a particular embodiment illustrated in figure 21, a base layer 9 is deposited on the substrate 1 and on the salient elements 8 so as to completely fill the zones arranged between the salient elements 8. The base layer 9 presents a larger thickness than the thickness of the salient elements (typically 1.7 times greater). The next step is planarization by chemical mechanical polishing of the base layer 9 so that the front faces of the base layer 9 and of the salient elements 8 form a common flat surface (figure 22) able to act as substrate for deposition of the sacrificial layer 2 (figure 23). If there is a risk of the salient

elements 8 being damaged during the planarization step, planarization of the CPM type is performed followed by etching up to the level of the front face of the salient elements 8.

The process is suitable for any type of sacrificial layer polymer (photosensitive resin, polyimide, PMMA, etc...) and is independent from any treatment of the sacrificial layer polymer (polymer strongly or weakly annealed or even not annealed, annealed in UV, having undergone an ion implantation, etc...). The process enables any geometry of the sacrificial layer to be achieved (narrow, broad, thick, thin, rectangular, round, etc. shape). There are no risks of scratching on the sacrificial layer and the substrate, nor are there any risks of tear-off of the sacrificial layer during the planarization step, the sacrificial layer at no time extending beyond the embedding layer.

Application of an etching sub-step during the planarization step (figures 12 to 14) and/or the use of a temporary layer (mask 7) on the sacrificial layer 2 (figures 15 to 19) moreover enables any risk of damage of the sacrificial layer 2 by the abrasives to be eliminated.

In the case where thermal treatment of the sacrificial layer is necessary (for example when the technological component fabrication steps comprise high temperature steps, i.e. at a higher temperature than the polymer deposition temperature), this will preferably be performed before the polymer etching step to prevent creep of the latter.